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Abstract

The role of nonvalence, e.g., sea quarks and/or meson) degrees of freedom in static electroweak baryon observables is briefly discussed.

1 Introduction

The constituent quark model is a useful descriptive tool in hadron spectroscopy. The empirical spectrum of mesons and baryons suggests that hadrons are largely composed of the spin-1/2 constituent quarks confined to $q\bar{q}$ and qqq systems. Naturally, one needs to understand these relevant degrees of freedom, their effective structure parameters and forces acting between them to reach the understanding of QCD in the confining regime. However, despite many phenomenological successes the fundamental question of the connection between the three (for baryons) (or the $q\bar{q}$ -pair, for mesons) "spectroscopic" quarks, bearing the quantum numbers of a given hadron, and the infinite number of the "current" (or fundamental) quarks required, *e.g.*, by the deep-inelastic lepton-hadron scattering, is still a problem. One can believe, that, among other available menses, the precision description of static electroweak properties of hadrons, while had been one of cornerstones of the constituent quark model itself, can still be of relevance for deeper understanding of fundamental question on the "constituency" of constituent quarks. One of aspects of this problem is the following. The diagonalized Hamiltonian matrix, including the contributions of all spin-dependent interactions between three constituent quarks, defines masses of the ground and radially and orbitally excited states of the nucleon and provides also the structure of baryon state vectors in the $SU(6) \times O(3)$ basis states[1, 2] thus giving the deviation of the F/D -values, parameterizing the electroweak current matrix elements, from the $F/D = 2/3$ that corresponds to participating states in the $\underline{56}$ -representation, as often assumed for the nucleon and lowest symmetrical radial excitation (presumably, the Roper resonance with mass ~ 1440 Mev). As discussed in ref.[3], if the Roper resonance would be something different from the $3q$ -radial excitation, belonging to the $\underline{56}$ -representation of $SU(6)$, *e.g.* the hybrid state, then total probability to find the $(\underline{56})$ - configuration in the nucleon state vector would be diminished and the F/D -value could rise up to the value found from a version of phenomenological analysis of the baryon magnetic moments and axial couplings[4, 6] with important implications for the polarized parton distributions of the nucleon (see, *e.g.*,[7] for the recent discussion).

In this section we consider some consequences from sum rules for the static, electroweak characteristics of baryons following mainly from the phenomenology of broken internal symmetries. We choose the phenomenological sum rule techniques to obtain, at the price of a minimal number of the model-dependent assumptions, a more reliable, though not as much detailed information about the hadron properties in question. The main focus will be on the role of nonvalence degrees of freedom (the nucleon sea partons and/or peripheral meson currents) in parameterization and description of hadron magnetic moments, both diagonal and non-diagonal, including the $N\Delta\gamma$ -transition moment. Earlier we have considered[4] a number of consequences of sum rules for the static, electroweak characteristics of baryons following from the theory of broken internal symmetries and common features of the quark models including relativistic effects and corrections due to nonvalence degrees of freedom – the sea partons and/or the meson clouds at the periphery of baryons.

Here, we list some of the earlier discussed [4, 5, 6] sum rules (we use the particle and quark symbols for corresponding magnetic moments):

$$\alpha_D = \frac{D}{F + D} = \frac{1}{2} \left(1 - \frac{\Xi^0 - \Xi^-}{\Sigma^+ - \Sigma^- - \Xi^0 + \Xi^-} \right) \quad (1)$$

$$\frac{u}{d} = \frac{\Sigma^+(\Sigma^+ - \Sigma^-) - \Xi^0(\Xi^0 - \Xi^-)}{\Sigma^-(\Sigma^+ - \Sigma^-) - \Xi^-(\Xi^0 - \Xi^-)} \quad (2)$$

$$= \frac{P + N + \Sigma^+ - \Sigma^- + \Xi^0 - \Xi^-}{P + N - \Sigma^+ + \Sigma^- - \Xi^0 + \Xi^-} \quad (3)$$

The D - and F - constants in Eq.(1) parameterize "reduced" matrix elements of quark current operators where $SU(3)$ symmetry-breaking effects are contained in the factorized effective coupling constants of the single-quark-type operators, while other contributions (*e.g.* representing the pion exchange current effects) are cancelled in Eqs.(1)-(3) by construction.

The nonzero ratio u/d is related to the chiral constituent quark model where a given baryon consists of three "dressed", massive constituent quarks. Owing to the virtual transitions $q \leftrightarrow q + \pi(\eta)$, $q \leftrightarrow K + s$ the "magnetic anomaly" is developing, *i.e.*, $u/d = -1.80 \pm 0.02 \neq Q_u/Q_d = -2$. Evaluation of the one-loop quark-meson diagrams done earlier [5] gives: $u/d = (Q_u + \kappa_u)/(Q_d + \kappa_d) \simeq -1.85$, the κ_q being the quark anomalous magnetic moment in natural units, if we take the $SU(3)$ -invariant quark-pseudoscalar-meson couplings, the physical masses for the π -, η -, K -mesons and the $m_{q(s)} \simeq 300(400)$ MeV. In the full $SU(3)$ -symmetry limit, when $m_q = m_s, m_\pi = m_\eta = m_K$, we return to $u/d = -2$, the ratio pertinent to the structureless current quarks. Evaluation of the "magnetic anomaly" via Eq.(3) turns out rather close to the result of the lowest order quark-pion loop diagrams with the pseudoscalar $qq\pi$ -coupling estimated via the Goldberger-Treiman relation at the quark level [9], while the terms of order $O(g_{qq\pi}^4)$ are negligible if the use is made of old calculations for magnetic moments of nucleons [10] to adapt them for the quark case through corresponding replacement of the coupling constants and masses of fermions. The ratio $s/d \simeq .64$ demonstrating the $SU(3)$ -symmetry

$$\frac{s}{d} = \frac{\Sigma^+ \Xi^- - \Sigma^- \Xi^0}{\Sigma^- (\Sigma^+ - \Sigma^-) - \Xi^- (\Xi^0 - \Xi^-)} \quad (4)$$

Now, we list some consequences of the obtained sum rules. The numerical relevance of adopted parameterization is seen from results enabling even to estimate from one of obtained sum rules, namely,

$$\begin{aligned} &(\Sigma^+ - \Sigma^-)(\Sigma^+ + \Sigma^- - 6\Lambda + 2\Xi^0 + 2\Xi^-) \\ & - (\Xi^0 - \Xi^-)(\Sigma^+ + \Sigma^- + 6\Lambda - 4\Xi^0 - 4\Xi^-) = 0. \end{aligned} \quad (5)$$

the necessary effect of the isospin-violating $\Sigma^0\Lambda$ -mixing. By definition, the Λ -value entering into Eq.(18) should be "refined" from the electromagnetic $\Lambda\Sigma^0$ -mixing affecting $\mu(\Lambda)_{exp}$. Hence, the numerical value of Λ , extracted from Eq.(18), can be used to determine the $\Lambda\Sigma^0$ -mixing angle through the relation

$$\sin \theta_{\Lambda\Sigma} \simeq \theta_{\Lambda\Sigma} = \frac{\Lambda - \Lambda_{exp}}{2\mu(\Lambda\Sigma)} = (1.43 \pm 0.31)10^{-2} \quad (6)$$

in accord with the independent estimate of $\theta_{\Lambda\Sigma}$ from the electromagnetic mass-splitting sum rule [8]. Of course, this approach is free of a problem raised by Lipkin[11] and concerning the ratio $R_{\Sigma/\Lambda}$ of magnetic moments of Σ^- and Λ -hyperons. With the parameters $u/d = -1.80$ and $\alpha_D = (D/(F+D))_{mag} = 0.58$, defined without including in fit the Λ -hyperon magnetic moment, we obtain

$$R_{\Sigma/\Lambda} = \frac{\Sigma^+ + 2\Sigma^-}{\Lambda} = -.27 \quad (vs \quad -.23 \text{ [12]}) \quad (7)$$

while in the standard nonrelativistic quark model without inclusion of nonvalence d.o.f. this ratio would equals -1 .

The experimentally interesting quantities $\mu(\Delta^+P) = \mu(\Delta^0N)$ and $\mu(\Sigma^{*0}\Lambda)$ are affected by the exchange current contributions and for their estimation we need additional assumptions. We use the analogy with the one-pion-exchange current, well-known in nuclear physics, to assume for the exchange magnetic moment operator

$$\hat{\mu}_{exch} = \sum_{i<j} [\vec{\sigma}_i \times \vec{\sigma}_j]_3 [\vec{\tau}_i \times \vec{\tau}_j]_3 f(r_{ij}), \quad (8)$$

where $f(r_{ij})$ is a unspecified function of the interquark distances, $\vec{\sigma}_i(\vec{\tau}_i)$ are spin (isospin) operators of quarks. Calculating the matrix elements of $\hat{\mu}_{exch}$ between the baryon wave functions, belonging to the 56-plet of $SU(6)$, one can find

$$\mu(\Delta^+P)_{\underline{56}} = \frac{1}{\sqrt{2}} \left(P - N + \frac{1}{3}(P + N) \frac{1 - u/d}{1 + u/d} \right). \quad (9)$$

where Eq.(24) may serve as a generalization of the well-known $SU(6)$ -relation [13, 14].

We list below the limiting relations following from the neglect of the nonvalence degrees of freedom

$$\Sigma^+[\Sigma^-] = P[-P - N] + (\Lambda - \frac{N}{2})(1 + \frac{2N}{P}), \quad (10)$$

$$\Xi^0[\Xi^-] = N[-P - N] + 2(\Lambda - \frac{N}{2})(1 + \frac{N}{2P}), \quad (11)$$

$$\mu(\Lambda\Sigma) = -\frac{\sqrt{3}}{2}N. \quad (12)$$

The numerical values of magnetic moments following from this assumption coincide almost identically with the results of the $SU(6)$ -based NRQM taking account of the $SU(3)$ breaking due to the quark-mass differences [15]. We stress, however, that no NR assumption or explicit $SU(6)$ -wave function are used this time. The ratio $\alpha_D = D/(F + D) = .61$ in this case and it is definitely less than $\alpha_D = .58$, when nonvalence degrees of freedom are included[4]. This is demonstrating a substantial influence of the nonvalence degrees of freedom on this important parameter.

3 The OZI-Rule and $SU(3)$ Symmetry Violation in Magnetic and Axial Couplings of Baryons

Here, we follow a complementary view of the nucleon structure, keeping the constraint $u/d=-2$, and the OZI-rule violating contribution of sea quarks, parameterized as $\Delta(N) = \sum_{q=u,d,s} \mu(q) < N | \bar{s}s | N > \neq 0$.

We shall refer to this approach [4] as a correlated current-quark picture of nucleons. We have then the following important sum rules (in n.m.)

$$\Delta(N) = \frac{1}{6}(3(P + N) - \Sigma^+ + \Sigma^- - \Xi^0 + \Xi^-) = -.06 \pm .01, \quad (13)$$

$$\mu_N(\bar{s}s) = \mu(s) \langle N | \bar{s}s | N \rangle = (1 - \frac{d}{s})^{-1} \Delta(N) = .11, \quad (14)$$

where the ratio $d/s=1.55$ follows from the correspondingly modified Eq.(4) (that is with Y replaced by $Y - \Delta$). By definition, $\mu_N(\bar{s}s)$ represents the contribution of strange ("current") quarks to nucleon magnetic moments. Numerically, our $\mu_N(\bar{s}s)$ agrees fairly well with other more specific models (see, e.g. [16]. Actually, our Eqs. (13) and (14) are equivalent, up to the common factor $-(1/3)$, which is the electric charge of the strange quark, to the half-sum of two relations in Ref.[17] that refer to $\mu_N(\bar{s}s)$ and where the ratios of effective magnetic moments of quarks in different baryons should be taken the same. We stress that the sign of our $\mu(\bar{s}s)$ is opposite to one of the central measured value in the experiment SAMPLE [18].

The calculated quantity indicates violation of the OZI rule and the strange current quark contribution $\mu_N(\bar{s}s)$ is seen to constitute a sizable part of the isoscalar magnetic moment of nucleons (or, which is approximately the same, of the nonstrange constituent quarks)

$$\frac{1}{2}(P + N) = \mu(\bar{u}u + \bar{d}d) + \mu(\bar{s}s) = .44, \quad (15)$$

$$BR\left(\frac{\overline{P}N \rightarrow \phi + \pi}{\overline{P}N \rightarrow \omega + \pi}\right) \simeq (10 \pm 2)\%, \quad (16)$$

reported for the s-wave $\bar{N}N$ – annihilation reaction [19].

Indeed, the transition $(\overline{P}N)_{s\text{-wave}} \rightarrow V + \pi$, where $V = \gamma, \omega, \phi$, is of the magnetic dipole type. Therefore, the transition operator should be proportional to the isoscalar magnetic moment contributions from the light u- and d-quarks and the strange s-quark, Eq.(25). The transition operators for the ω - and ϕ -mesons are obtained from $\mu(\bar{q}q)$ and $\mu(\bar{s}s)$ through the well-known vector meson dominance model (VDM). Using the "ideal" mixing ratio $g_\omega : g_\phi = 1 : \sqrt{2}$ for the photon–vector–meson junction couplings and $\mu_\omega : \mu_\phi = \mu(\bar{q}q) : \mu(\bar{s}s)$ we get

$$BR\left(\frac{\overline{P}N \rightarrow \phi + \pi}{\overline{P}N \rightarrow \omega + \pi}\right) \simeq \left(\frac{\mu(\bar{s}s)}{\sqrt{2}\mu(\bar{u}u + \bar{d}d)}\right)^2 \left(\frac{p_\phi^{c.m.}}{p_\omega^{c.m.}}\right)^3 \simeq 6\%, \quad (17)$$

which is reasonably compared with data.

To estimate possible influence of the $SU(3)$ breaking in the ratio of the weak axial-to-vector coupling constants we adopt the following prescription suggested by the success of our parameterization of the baryon magnetic moment values within constituent quark model. In essence, we assume that the leading symmetry breaking effect is produced by different renormalization of the $\bar{q}qW$ - strangeness-conserving and strangeness-nonconserving vertices with the participation of the constituent quarks. As to the baryon wave functions and the transition matrix elements of the standard octet (i.e. Cabibbo) currents, they will fulfill separately, within the strangeness-conserving or, respectively, the strangeness-nonconserving coupling constants. Hence we have two sets of the $SU(3)$ -symmetry relations but, in general, with different values of F - and D -type coupling constants in each set.

So that, to obtain the contributions of the u-, d-, and s-flavoured quarks to the "proton spin" (or, rather to certain combination of the axial current matrix elements), denoted by $\Delta u(p)$, $\Delta d(p)$ and $\Delta s(p)$, the use should be made of baryon semileptonic weak decays with ($\Delta S = 0$), treated with the help of the exact $SU(3)$ -symmetry. It has been shown in Ref.[20] that when both the strangeness-changing ($\Delta S = 1$) and strangeness-conserving ($\Delta S = 0$) transitions are taken for the analysis, then $(D/F + D)_{ax}^{\Delta S=0,1} = .635 \pm .005$ while $(D/F + D)_{ax}^{\Delta S=0} = .584 \pm .035$ (which is more close to $(D/D + F)_{mag}$).

We list below two sets of the Δq -values, we have obtained from the data with inclusion of the QCD radiative corrections (e.g.[21] and references therein) : $\Delta u(p) \simeq .82(.83)$, $\Delta d(p) \simeq -.44(-.37)$, $\Delta s = -.10 \pm .04(-.19 \pm .05)$, where the values in the parentheses correspond to $\alpha_D = (D/D + F) = .58$. Concerning the very $g_a(\Delta S = 1)$ -constants, we mention the following options. In all but one [22] analyses of the hyperon β -decays, the absence of the "weak electricity" form factor $g_2(Q^2)$ due to induced second class weak current has been postulated from the very beginning. Following this way and taking $g_a^{exp}(\Sigma^- \rightarrow n) = -.34 \pm .024$, one gets [20] $(F/D)_{\Delta S=1} = .575$, demonstrating difference from $(F/D)_{\Delta S=0} = .72$ and the different tendency of deviation from $(F/D)_{SU(6)} = 2/3$, the fact which has to be understood dynamically. The fit to all $\Sigma^- \rightarrow ne\bar{\nu}$ decay data of Ref. [22] with $g_2 \neq 0$ yields $g_a = -.20 \pm .08$ and $g_2 = +.56 \pm .37$.

One cannot then define $(F/D)_{\Delta S=1}$ because data for all other hyperons have been treated under the assumption $g_2 = 0$. However, noting close numerical values of two quantities

$$F - D = g_a^{exp}(\Sigma^- \rightarrow n) = -.20 \pm .08,$$

$$F - D = g_a^{exp}(n \rightarrow p) - \sqrt{6}g_a^{exp}(\Sigma \rightarrow \Lambda) = -.19 \pm .04,$$

one can suggest, in this particular case, the universal value $(F/D)_{\Delta S=0,1} = .72$ to get

$$g_a(\Lambda \rightarrow p) = F + \frac{1}{3}D = .77; \quad (.718 \pm .015), \quad (18)$$

$$g_a(\Xi^- \rightarrow \Lambda) = F - \frac{1}{3}D = .28; \quad (.25 \pm .05), \quad (19)$$

$$g_a(\Xi^0 \rightarrow \Sigma^+) = F + D = 1.26; \quad (1.32 \pm .20) \quad (20)$$

where the values in parentheses have been derived [12, 23] from the analyses of data with the additional constraint $g_2 = 0$. The most significant difference in two sets of g_a values is seen for the $\Lambda \rightarrow pe\bar{\nu}$ decay which, therefore, lends itself as the best candidate for an alternative treatment of available or improved new data with the "weak-electricity" g_2 -constant taken as a free parameter to be determined from data simultaneously with the axial-vector and weak-magnetism constants.

4 Concluding remarks

Besides importance of resolution of the problem on the presence and quantitative role of the weak second-kind current and corresponding form factors in the hyperon β -decay observables, one can mention also about major theoretical interest in the careful study of the strangeness-conserving $\Sigma^\pm \rightarrow \Lambda e^\pm \nu(\bar{\nu})$ transitions which would not only prove (or disprove) hypotheses about dependence of (F/D) -ratios on the ΔS , labelling the transitions, but also would provide information on the isospin breaking effects underlying the $\Lambda - \Sigma^0$ - mixing.

There is presently well-justified experimental and theoretical interest concerning the question of hidden strangeness in the nucleon. The SAMPLE collaboration has recently reported the first measurement of the strange magnetic moment of the proton [18], which turned out very close to zero, but with rather large experimental errors, "touching" both significant positive values of μ_s (in our normalization), as majority models also predict, as well as the opposite sign value, claimed mainly within chiral soliton models (*e.g.* [24, 25], and references therein). For a detailed understanding about the strength of the various strange operators in the proton one has to wait until the dedicated programs at JLab, BATES (MIT) and MAMI (Mainz) will be fulfilled on the measurement of parity violation in the helicity dependence of electron-nucleon scattering in wider range of the momentum-transfers to separate the contributions of the charge, magnetic and axial terms, thus providing data about the basic quark structure of the nucleon.

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